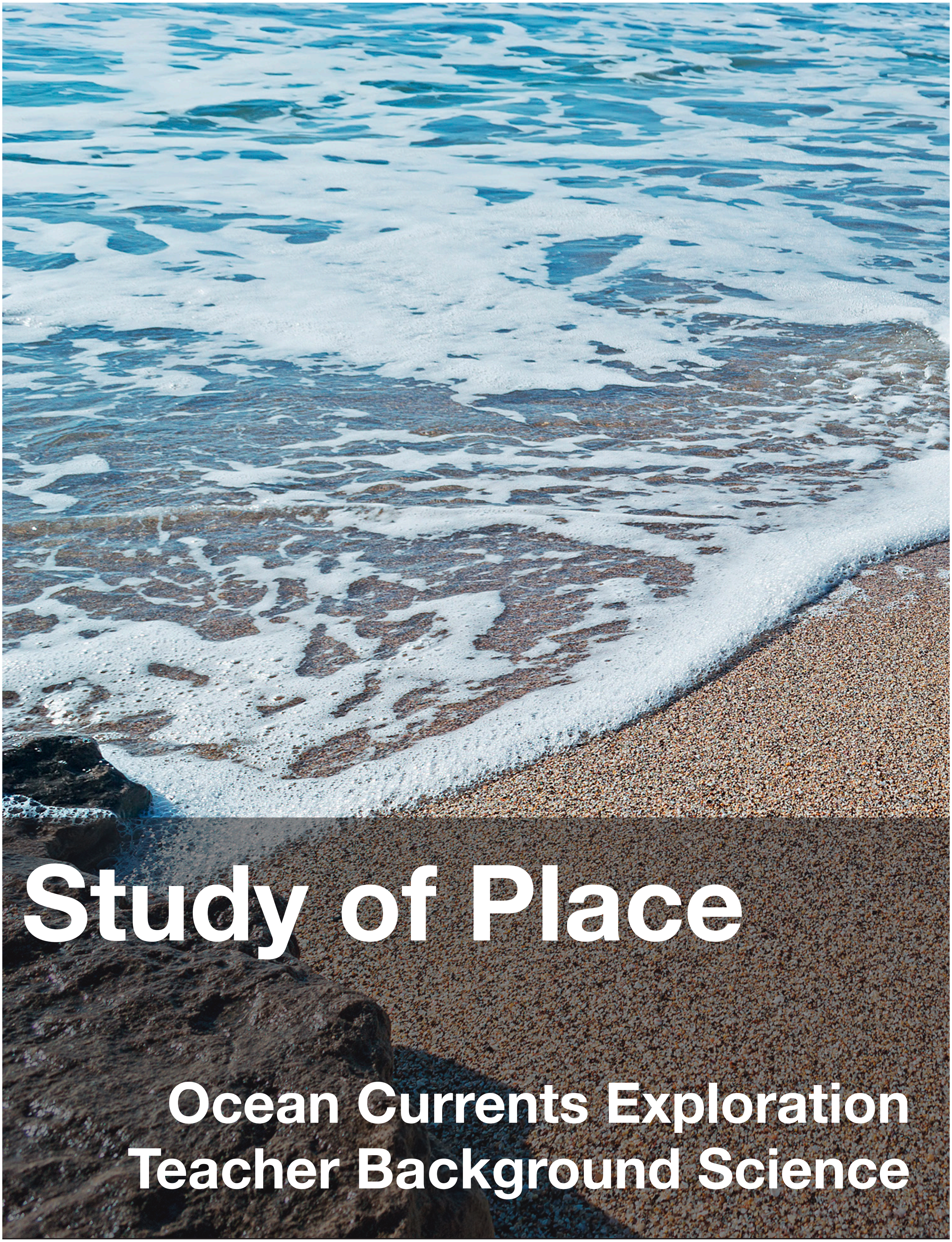

Study of Place

Ocean Currents Exploration
Teacher Background Science

Chapter 5

Exploring the Gulf Stream from Above

What the Teacher Might Want to Know

About Benjamin Franklin and the Gulf Stream

Teachers should be familiar with the story of Benjamin Franklin's charting of the Gulf Stream and with transatlantic travel in the colonial era. Dr. Maurice Isserman has written an account of this chapter of science history especially for this curriculum called Ben Franklin and the Gulf Stream. Deborah Heiligman's book The Mysterious Ocean Highway is another helpful and enjoyable resource.

About student understanding of spatial images

Students' familiarity with maps usually begins with symbols and names associated with the outline of a familiar physical space, e.g., a map of the classroom. Later, students work with maps of larger areas, learning that maps are created for different purposes and use different conventions according to those purposes. A political map, for example, will show lines that represent the boundaries of countries or state, while a topographical map will show contour lines to represent elevations. Students have seen historical charts in their social studies texts, but are not asked to compare them to other representations of the same location. By requiring these comparisons, we guide students toward understanding that different representations reveal different information. We also aim to introduce the idea of the complexity of the Earth system with this approach. Technologies such as GIS (Image 5.2), and computer modeling (Image 5.5) may be new to middle school students, but they probably have heard of data gathered by satellite sensors (Images 5.3, 5.4, and 5.6). Reading the color keys and velocity vectors will also be new for most students. These types of intellectual exercises which tap into your students' spatial intelligence will contribute toward their abilities to interpret data about the world they live in. The cartography article, How did people make maps before there were maps to copy? will give your students some historical background as well.

About the human eye as a sensor

The human eye is one example of a sensor. Light passes through the pupil, the lens, and the transparent jelly filling the cavity of the eye, until it falls on the retina. The retina is made up of millions of tiny sensory nerve endings that respond to a small band of wavelengths of the electromagnetic spectrum called "visible light." Chemical changes in the retinal cells trigger nerve impulses that relay information about the intensity of light to the brain. Nerve cells in the brain then interpret the information and we "see" an image of the object.

About satellite images

Many modern images of Earth are created from data collected by sensors carried aboard satellites. Some sensors can detect forms of light energy that are invisible to the human eye and to ordinary cameras. For example, certain electronic sensors can measure and record the amount of infrared light being reflected or emitted by Earth at different wavelengths and bandwidths. That information can be digitized and either stored on satellite computers or transmitted to Earth for storage. The stored data can later be retrieved and converted into an image by computer software.

More information about satellite images

The smallest components of these images are called pixels. The resolution of the image that is produced depends on how large an area is represented by each pixel. The larger the area represented by each pixel, the lower the resolution. In satellite images, each pixel is assigned a value that represents the amount of light that was reflected or emitted by a specific area on Earth.

About the history of satellites

The first Earth-orbiting satellite, Sputnik, was launched in 1957 by the Soviet Union. The launch sparked a "space race" between the Soviet Union and the United States. In 1961, the United States sent the first American, Alan Shepard, into space on a flight lasting 15 minutes. The next year, American John Glenn made a triple orbit of Earth. Satellites are now commonplace; in fact, more than 3,500 satellites orbit Earth every day. These satellites are used for many purposes including communication, weather forecasting, environmental monitoring, and navigation.

About the images in this chapter

Image 5.1, created in 1769, is an old-style chart that is similar to the kind of maps that students will have used to learn the location and names of continents, oceans, countries, and states. Like many maps of its era, this chart shows evidence of recycling. In this case, the ocean current and sailing directions were engraved onto an existing chart. The original chart is quite large, measuring 87 cm by 97 cm; students are looking at only a small part of it. This chart has the names of places, including U.S. states, but it does not show salinity, temperature, productivity, or other scientific information that would be useful for a complete understanding of the Gulf Stream.

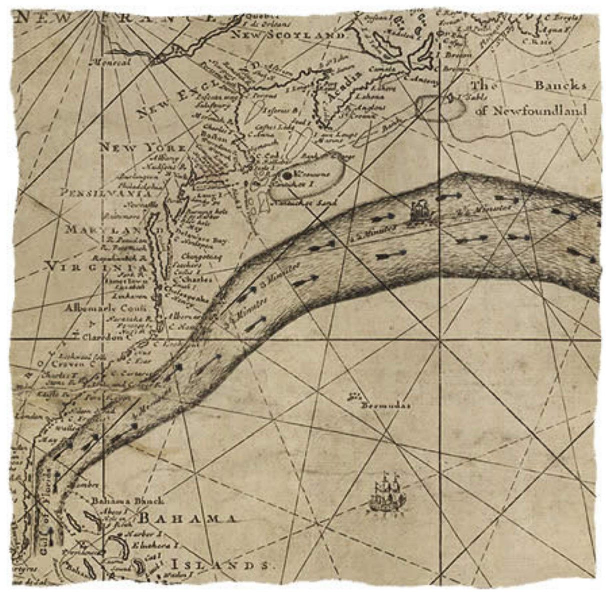

Image 5.1 - Franklin-Folger Gulf Stream Chart

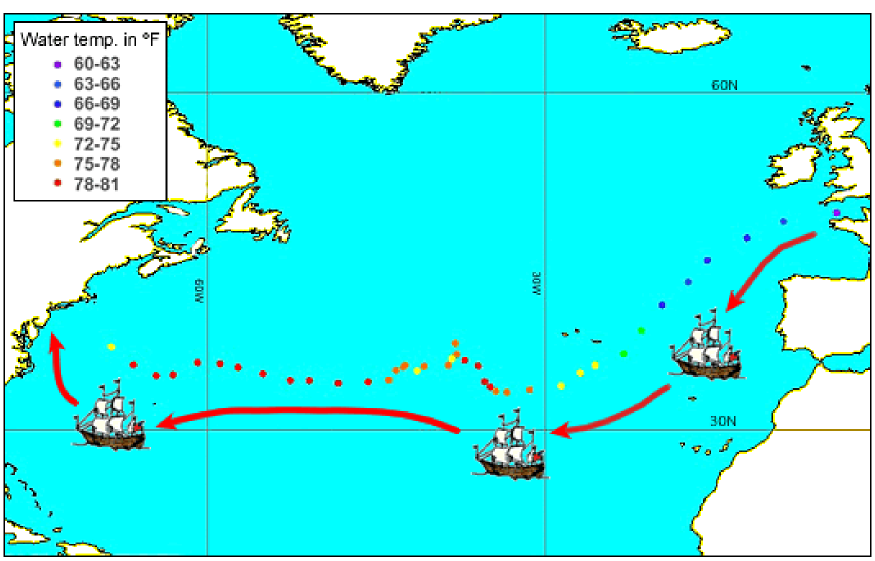

Image 5.2 - Franklin's Ocean Temperature Readings

Image 5.2 is a Geographical Information Systems (GIS) layer map. It was created to show the water temperature data that Benjamin Franklin collected over several weeks on his voyage from France to America in 1785. GIS mapping is useful for finding correlations between different data sets. By layering one set of data over another, the GIS technology can identify patterns of similarity and difference. The technique is similar to placing transparencies with different types of data on top of each other to see if there are correlations.

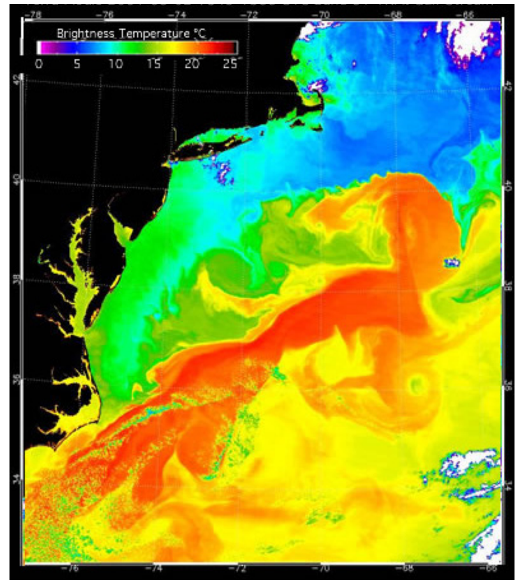

Image 5.3 - Sea Surface Temperature

Image 5.3 is a satellite image that shows sea surface temperatures. It was created from data collected by sensors that detect infrared light. These sensors are accurate to 0.25°C. Satellite sensors are not as accurate as conventional water-sampling devices, which are accurate to 0.001°C, but they provide global coverage in "real time," something that a water gauge cannot do.

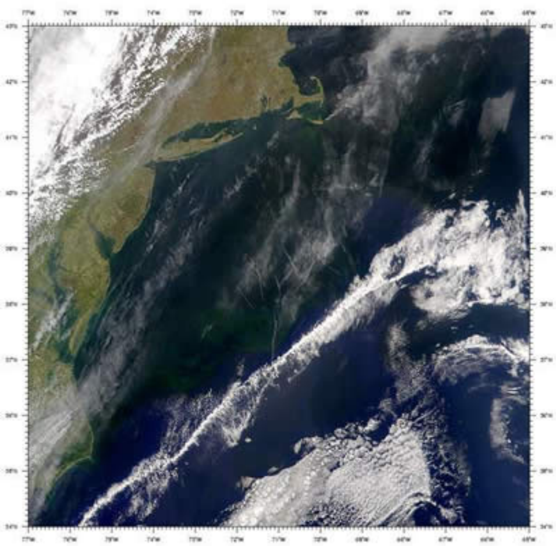

Image 5.4 - Gulf Stream from Space

Image 5.4 is a satellite image that shows the distribution of phytoplankton (microscopic plants) in Earth's oceans. It was created from data collected by sensors that detect visible light. From the colors, scientists can judge the amount of phytoplankton in an area. Waters rich in phytoplankton are green, whereas unproductive waters are deep blue. Phytoplankton are important to the balance of life on Earth. They generate at least half the oxygen that humans breathe, and they absorb a significant amount of the carbon dioxide that is produced by animal respiration and the burning of fossil fuels.

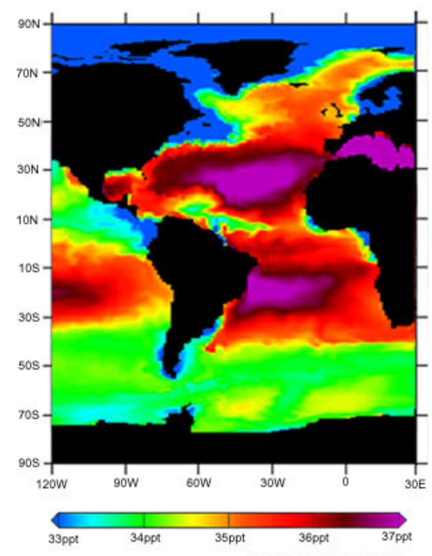

Image 5.5 - Sea Surface Salinity

Image 5.5 is a computer-generated representation of ocean salinity. It was made using a climate-modeling program. Programmers created the model by entering very large data sets and equations for physical phenomena (e.g., land temperatures, ocean circulation, atmospheric activity, and changes in land, ice and polar ice shelves) and allowing them to interact. Scientists can enter a new data set (e.g., a set of salinity readings) for a particular start time and then allow the model to "evolve" to show changes over time as the introduced variable is affected by the other phenomena in the model. Although computerized climate models are useful for making general predictions about the physical world, their predictive power is limited by phenomena that are still poorly understood, such as the effect of solar and infrared radiation on clouds and the role of turbulence in the ocean.

The salinity range in Earth's oceans is very narrow, from 33 parts per thousand to 37 parts per thousand. Yet even these small salinity differences can cause density differences that help drive ocean currents.

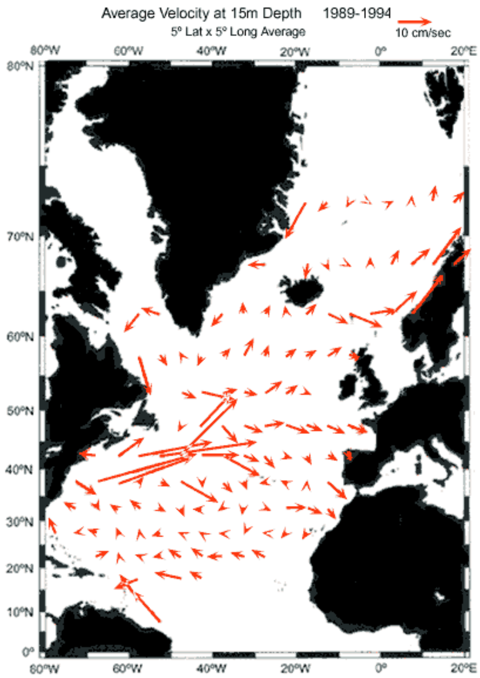

Image 5.6 - Atlantic Ocean Current Speed and Direction

Image 5.6 depicts a five-year average of surface current velocity in the Atlantic Ocean. Scientists collected the data from the movement of free-floating ocean buoys. Fully instrumented, they can measure not only ocean velocity, but also wind velocity, sea surface temperature, wave height, air temperature, and barometric pressure. Buoy data are typically transmitted to orbiting satellites, which relay the information back to tracking stations on Earth.

Notice the large arrows between 40°N and 50°N. This is the Gulf Stream. Also notice how large Greenland appears on this map. Greenland is not really this big; the distortion is a function of the projection used to make the map. If you look at the latitude markings on the side of the map, you will see how the distortion progresses from south to north.

Chapter 6

Density Driven Currents

What the Teacher Might Want to Know

About density

Middle school students often think of density in terms of how heavy something is or how much of something there is. If an object floats on top of a liquid, students will often state that the object is lighter than the liquid. Similarly, if one liquid floats on top of another liquid, students will often state that there is less of the floating liquid than of the other. Students usually think of just one variable, mass or volume, as affecting the outcome; it is not intuitive for them to suggest the involvement of two variables. This chapter tries to correct these misconceptions by having students do the following:

- Take three liquids with the same volume but different densities and see how they interact.
- Take these same liquids, decrease the volume of the one that sank, and again see how they interact. From this experiment, students will begin to understand that volume alone does not determine whether a substance sinks or floats.
- Calculate mass divided by volume (m/v) for different amounts of each liquid. Students will find that each liquid has a unique m/v.
- What determines what sinks or floats is density, which is calculated by the following formula: **density = mass/volume.**

The density of fresh water is 1 g/cm3. The density of sea water is always greater than that of fresh water, although the exact density of sea water varies with its salinity, temperature, and the pressure exerted upon it.

About salinity

Sea water is made up of different salts, all in the form of ions. There are over 70 types of ions in sea water, but the six predominant ions are chloride, sodium, sulphate, magnesium, calcium and potassium. The salinity of water is expressed in terms of salt concentration in “parts per thousand” or ppt. All ocean water is salty but not equally so. The range of salinity for most of the ocean’s surface waters is 32.5 ppt to 37.5 ppt.

The exact salinity of sea water at a particular location depends on four factors:

Evaporation. Salinity increases when more fresh water leaves an environment than is added to it. Evaporation takes away fresh water so areas with high rates of evaporation often have high salinity. Evaporation rates are high in places that experience a large difference between water temperature and air temperature, for example at the poles, where the water is significantly warmer than the air. The Gulf Stream also has a high evaporation rate since it is so much warmer than the surrounding air.

Precipitation. In contrast to evaporation, precipitation decreases salinity by adding fresh water to an environment. Precipitation is highest around the Equator and is lowest at the poles.

River runoff. River runoff decreases ocean salinity by introducing fresh water into the environment. For example, the Black Sea has a salinity of only 15 ppt because it is so diluted from river runoff. Similarly, the Amazon River, which has a very large output of fresh water, contributes to the low sea surface salinity in the west tropical Atlantic Ocean.

Sea Ice. The seasonal fluctuations of sea ice affect the salinity of the arctic seas. When sea water freezes in winter, most of the salt is expelled from the ice; as the salt enters the surrounding water, it sinks below the ice, increasing the water's salinity. When the ice melts in spring, large stores of fresh water are released and salinity decreases.
As salinity of water increases, so does its density. When salt is added to water, the mass of the water increases, while the volume stays the same. Therefore, the mass per unit volume (density) increases. As more and more salt is added to water, the salt is more closely packed, increasing the density.

About temperature differences and density

Cold water is more dense than warm water. As a liquid cools, its molecules slow down and move closer together. As they move closer together, density increases. As water warms, it expands. When it expands, the molecules move further apart and the liquid becomes less dense. Thus, water at the poles, where water temperatures are in the 30s, is more dense than water at the Equator, where water temperatures can be in the 80s.

About thermohaline circulation

"Thermohaline circulation" describes the global movement of currents that are created by differences in water temperature and salinity. We can trace the path of thermohaline circulation beginning at high latitudes, where cold ocean water sinks because of its relatively high density. In the Northern Hemisphere, this sinking takes place in two locations: in the Labrador Sea and in the Norwegian-Greenland Sea. (Deep sinking to 2000-3000 meters occurs only in the North Atlantic, not in the North Pacific because while the waters of the North Pacific are very cold, they are not as salty as the waters of the North Atlantic. Because they are less dense, they do not sink as deep.) In the Southern Hemisphere, water from the Southern Ocean off the coast of Antarctica sinks to great depths because it is so cold.

Thus Earth's deep ocean basins are filled with waters from the northern North Atlantic and those that sink near Antarctica. This deep water cannot keep accumulating, and therefore, as new water moves in, the deep water is displaced and rises to the surface where it is warmed. Once at the surface, the waters flow back to the regions where sinking occurs, thus completing the cycle.
When the waters sink at high latitudes, not only are they denser than the surface waters, they are also denser than the waters at lower latitudes. The more dense waters "push" on the less dense water. Water moves from high pressure (higher density waters) to low pressure (less dense waters). In this manner the deep waters at high latitudes (which were recently at the surface) spread throughout the rest of the ocean, displacing less dense water. Density differences drive ocean circulation not only when heavy water is over light water, but also when heavy water is NEXT to light water in the same horizontal plane.

Here is a good metaphor for explaining this concept to your students: Think of a warm room and a cold room, separated by a door. If you are in the warm room and you place your hand at the crack at the bottom of the door, you will feel the cold air rushing in. In this way, once the dense waters sink, they continue to move to other parts of the ocean because they are denser than the other waters sitting on the ocean floor.

This sinking and rising, along with the horizontal movement of water to and from the sinking regions, creates a “conveyor belt” of movement from the sinking regions to the rest of the ocean.

About heat transfer

In the 1700s, Joseph Black, a Scottish physician, conducted an experiment using metal, stone, salt, wood, cork, and several different liquids. He started all materials at different temperatures and put them in an unheated room. After leaving them in the room for some time, he noticed that the warmer materials had cooled and the cooler materials had warmed. With this experiment, Black demonstrated the idea of heat transfer and thermal equilibrium. When two objects are at different temperatures, heat transfers from the warmer one to the cooler one. This transfer continues, theoretically, until both objects reach the same temperature. When two have reached the same temperature, they are said to be in thermal equilibrium.

The idea of heat transfer is relevant to ocean circulation. The Earth does not heat evenly; the amount of heat at a particular location on Earth is determined by the amount of energy received from the Sun and the amount of energy the Earth reradiates per unit area. Since the Sun hits the Equator at a direct angle, but at increasing angles at higher latitudes, over the course of the year the Equator receives more solar energy per unit area than other locations. The ocean conveyor belt helps redistribute the heat, for example, by transporting the warm water in the Gulf Stream to the cool latitudes of northern Europe.

Chapter 7

Wind Driven Currents

What the Teacher Might Want to Know

About measuring and reporting latitude and longitude

Latitude and longitude are measured in degrees, minutes, and seconds. There are 60 minutes in a degree and 60 seconds in a minute. Degrees are indicated by °. Minutes are represented by ‘ and seconds by “. Gallup, New Mexico is located between 35 and 36 degrees north latitude and 108 and 190 degrees west longitude. Its position is fully reported as 35° 31’ 32” N, 108° 46’ 47” W.

About cargo spills

When they study currents, oceanographers often take advantage of cargo spills. Every year, manufacturers ship more than 100 million containers of cargo across the oceans. Many of these containers are stacked on the decks of ships. When severe weather arises, they can get thrown overboard. In fact, more than 10,000 fall overboard each year. This may sound like a lot, but it is only .01%, or 1/10,000 of all containers that are transported. While there are negative consequences of these spills, including profit losses and damage to the environment, they do help oceanographers understand currents better. By following the course of the spilled materials, researchers can map currents more accurately.

One oceanographer who is very involved in tracking items from cargo spills is Curtis Ebbesmeyer of Evans-Hamilton Inc., an environmental consulting firm that researches oceanographic questions. Ebbesmeyer was used to tracking currents by dropping buoys and drift cards into the ocean. But when he learned about a major spill of Nike® sneakers in 1990, he immediately realized that tracking lost cargo would give him more data points. The reason is simple. While scientists routinely drop 500 or 1000 drift cards for an experiment, cargo spills often contain millions of items, allowing for a greater number of pathways to be studied.

Nike® sneaker spill: On May 27, 1990, the Hansa Carrier encountered a storm in the North Pacific Ocean. The storm sent 21 containers off the deck and into the ocean. Five of the containers held 80,000 sneakers, including running shoes, cross trainers, tennis shoes, and walking shoes. By the following November, the North Pacific Current had transported the sneakers to the Washington coast. Driven by winds and currents, thousands of sneakers traveled from the west coast of the United States to Vancouver, British Columbia. By April of 1991, the sneakers had moved as far south as southern Oregon, following the seasonal change in wind direction from southerly in the winter to northerly in the spring. Ebbesmeyer learned of the recovery location from beachcombers. Altogether, 1,600 shoes were recovered and recorded, helping researchers map the North Pacific currents more accurately.

Oceanographers have studied many other cargo spills, including losses of drums containing arsenic and rubber bath toys. All of these items have been used to help map ocean currents.

About Winds

The formation of global wind systems: Temperature differences on the planet drive wind circulation. Global winds form due to the unequal heating of Earth. Some locations on the planet receive more solar energy per unit area than other locations. The Equator receives much more energy than it emits. In contrast, the poles receive less solar energy than they radiate back into space. As a result, there is an unequal distribution of heat energy on the planet. The atmospheric winds work to reduce the heat imbalance between high and low latitudes. As air heats up the Equator, it lifts up and spreads out to the North and South Poles. The air at the poles sinks as it cools, spreading out and moving toward the Equator.

Prevailing winds: In 1735, George Hadley, a British meteorologist, made a simple model of wind circulation. According to this model, which describes a convection cell, warm air rises at the Equator and moves toward the poles. When the warm air arrives at the poles, it cools and sinks because it has become more dense. The cooled air then travels back to the Equator at lower altitudes. At the Equator, the air is warmed and rises again, continuing the cycle.

Hadley had it partly right. Wind does move between the Equator and the poles as it redistributes heat across the planet. But because of the rotation of the Earth and the Coriolis force, it does not take a straight path. Once this force is taken into account, we must think of wind circulation in three cells, not just one.

In this three-celled model, air rises at the Equator and travels to about 30° latitude as upper-level winds, then sinks as it loses heat and become more dense. Assuming the perspective of the Northern Hemisphere, here's what happens. At 30°, some of the air goes back to the Equator as lower-level winds while some continues north. The air that returns to the Equator is deflected to the right (west) and creates the trade winds, also called the northeasterly trade winds because they travel from the northeast to the southwest. (Winds are named according to the direction from which they originate not the direction they blow.) The winds that continue north at 30° are also deflected to the right (east). These winds, which prevail from 30° N to 60° N, are called the westerlies because they are traveling from the west to the east.

The first cell, describing the air from the Equator to 30°, is called the Hadley Cell. The second cell, describing the air from 30° to 60°, is called the Ferrell Cell. These are the two cells that your students will be most concerned with. The third cell, from 60° to 90°, is called the Polar Cell.

About the formation of wind-driven currents

Several factors affect wind-driven currents. The primary factor is wind, but three other factors also come into play: landmasses, the Coriolis force, and the pressure gradients that are created by the wind. This activity focuses on wind and landmasses, which are easily understood by most middle school students. If your students are advanced, you may want to introduce the Coriolis force. Pressure gradients are not within the scope of this module.

Wind: In general, ocean currents follow wind circulation and help redistribute heat on the planet.

Landmasses: Landmasses affect currents by deflecting the flow of water. This phenomenon is discussed in the section on gyres, below.

Coriolis force: The Coriolis force describes the apparent deflection of winds, water, airplanes, rockets, and other objects moving on or above Earth. This deflection is to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The Coriolis force is a "pseudo-force" force—not a true force but rather a result of Earth's rotation.

About gyres

Gyres are circular ocean currents produced by winds, landmasses, and the effect of Earth's rotation. Gyres arise in both the Northern Hemisphere and the Southern Hemisphere in part due to prevailing winds. One system of prevailing winds are trade winds that blow from the east between the Equator (0°) and 30° in both hemispheres. The westerlies are another system of prevailing winds that blow from the west between 30° and 60° in both hemispheres. These opposing wind systems contribute to the formation of ocean gyres between 20° and 40°, both north and south of the Equator.

Gyres form because the action of wind and rotation create currents that eventually encounter landmasses; the landmasses deflect the currents, causing them to loop around in circles. For example, if water in the North Atlantic Ocean is traveling westward, it will eventually encounter a landmass, North America. Once it bumps up against this continent, it will be deflected north or south. The water that is deflected north will head back out to the ocean moving eastward due to the influence of the westerlies and rotation. Eventually the water will encounter a landmass to the east, probably Europe, and will again be deflected north or south. The water that is deflected to the south will head back out to the ocean moving westward due to the influence of the trade winds and rotation, creating a loop and beginning the cycle all over again. If Earth had no landmasses, the ocean would not form gyres. Notice that there are no landmasses between 50°S and 60°S; neither are there gyres. Instead, water travels the circumference of Earth in a circumpolar current.

Chapter 8

Currents and Heat Transfer

What the Teacher Might Want to Know

The Gulf Stream as a Transporter of Heat Energy

About specific heat capacity

In this activity, students learn that water takes longer to heat to a certain temperature than sand. In scientific parlance, water has a greater specific heat capacity. Specific heat capacity is the amount of energy required to change the temperature of one gram of a substance by 1°C. The more energy that is required to change the temperature, the greater the specific heat capacity. The units used to describe specific heat capacity are usually in joules per gram per degree C.

The specific heat capacity of water is 4.184 joules per gram per degree C. The specific heat capacity of sand is 0.8 joules per gram per degree C. In other words, it takes about five times as much energy to increase the temperature of water by one degree Celsius as it does to increase the temperature of the same amount of sand by one degree.

The differences between sand and water in their capacity to store energy resides at the molecular level. Energy added to water increases two things: its internal energy* PLUS energy stored by breaking hydrogen bonds between water molecules. In effect, the broken bonds represent an energy reservoir. When the internal energy of water drops as it passes into the air (shown by the temperature dropping), the hydrogen bonds re-form, thereby releasing the stored energy also.

*The energy in heated sand is internal energy only (no chemical bonds are broken when sand heats up). Internal energy is sometimes referred to as vibrational, or kinetic energy because the molecules move faster; it is sometimes called thermal or heat energy. We use the phrase heat energy when discussing internal energy in the student materials.

About the ocean as a heat reservoir

Given its high specific heat capacity, water is able to store a tremendous amount of energy. Consequently, Earth's oceans play an important role in the planet's energy system. Oceans store the heat they gain in summer and slowly release it over the following winter. They also transport this heat from warm regions to cooler ones. For example, the Gulf Stream stores the heat it gains in tropical regions of the Atlantic Ocean and then transports it to northern Europe.

Newton's Law of Cooling: According to Newton's Law of Cooling, the rate at which water will cool, transferring heat to the air above it, is proportional to the difference in temperature between the water and its surrounding environment. That is, water will cool more quickly if there is a large difference between the temperature of the water and the air above it than if there is a smaller difference.

The Gulf Stream does not lose much heat to the atmosphere until it reaches approximately 40°N, where the air temperatures are much colder. The strong temperature difference drives a huge heat flux from the ocean to the atmosphere. So, the Gulf Stream does not lose heat evenly. The heat loss is focused on the latitudes from 40°-50°N, where the temperature difference is greatest.

To help students understand how the ocean serves as a heat reservoir, you might cite the following example:

On June 1, the water off the coast of Ocean City, Maryland has an average temperature of 16ºC; on September 1, it is 22ºC. By September, the water has stored much of the heat from the sun that has been shining on it all summer. At 17ºC, the average water temperature in October is still warmer than it was in June.

About how the Gulf Stream affects temperatures in Europe

The Gulf Stream receives and stores heat energy in the tropics, but it cools as it moves northeastward into the North Atlantic Ocean. The heat energy that it received in the Gulf of Mexico and the Straits of Florida cannot just "disappear," for according to the law of conservation of energy, energy cannot be created or destroyed. Rather, the heat energy that the Gulf Stream held is transferred to the air, warming the winds that blow across Northern Europe. For this reason, cities east of the Gulf Stream are warmer than cities at the same latitude to the west of the Gulf Stream. For example, Tromso, Norway lies at 69º42' N and has an average January temperature of –5ºC, while Iqaluit, Canada, which is at approximately the same latitude, has an average January temperature of –22ºC.

Climate Change

About carbon dioxide

The natural decomposition of organic material produces 220 billion tons of carbon dioxide each year. This is 95 percent of all carbon dioxide produced on Earth. Other natural sources of carbon dioxide are volcanic eruptions and plant and animal respiration. Most of Earth's carbon dioxide is stored in sinks, such as the oceans and plants, which remove carbon dioxide from the atmosphere. Oceans remove about 92 billion tons of the gas from the atmosphere each year; land vegetation removes an additional 61 billion tons. When the sinks can't hold any more carbon dioxide, the gas accumulates in the atmosphere.

In addition to natural sources, human activity produces carbon dioxide. In fact, carbon dioxide levels are now 30 percent higher than pre-industrial levels, primarily because of the carbon dioxide produced by deforestation and the burning of fossil fuels. This excess carbon dioxide exceeds the capacity of Earth's sinks, so it enters the atmosphere.

About the greenhouse effect

When sunlight reaches Earth, some of the energy is absorbed by the land and oceans and is later radiated back toward space. (Some of the sun's energy is immediately reflected back into space without being absorbed.) But little of this energy escapes the atmosphere. Instead, greenhouse gases absorb approximately 88 percent of the energy and radiate it back to Earth. As a result, the planet is significantly warmer than it would otherwise be, a phenomenon called the greenhouse effect. If not for the greenhouse effect, it would have been too cold for life to have arisen on Earth.

The increase in atmospheric carbon dioxide caused by human activity makes it more difficult for heat to escape our atmosphere. Consequently, Earth's temperatures have been rising and are predicted to continue rising. Using computer models to simulate the climate's response to different scenarios, scientists can make general predictions about future climate changes. When scientists use these models to simulate a doubling of carbon dioxide in the atmosphere, they find that Earth's temperature rises between 1.5ºC and 4.5ºC.

About the effect of rising temperatures on marine organisms

Coral bleaching: When ocean temperatures increase, coral reefs lose their beautiful colors, becoming "bleached," and can die. In 1998, the warmest year on record, extensive and catastrophic worldwide coral bleaching occurred.

Change in distribution and range of organisms: When ocean temperatures increase, some marine organisms move to cooler waters. Increasing temperatures cause the northward migration of species that formerly inhabited more southern locations.

I***ncreasing mortality of zooplankton:*** The number of zooplankton (microscopic marine life) in several areas has decreased as ocean temperatures have increased. Since zooplankton are the first link in the ocean food web, a significant decline in the population of zooplankton could affect many other populations including mussels, fish, birds, and baleen whales.

Rising sea level: Many scientists estimate that sea levels are currently rising about 2 mm per year. This is a significant change from the annual increase over the past 3,000 years, which has averaged 0.1 mm to 0.2 mm. This increase has been attributed, in part, to increasing ocean temperatures.

Changes to Thermohaline Circulation and Current Slowing of the Ocean Conveyor Belt

About past changes in thermohaline circulation

At the end of the last glacial period 11,000 years ago, Earth went through a post-glacial cold period. During this period, called the "Younger Dryas" period, temperatures in Northern Europe decreased by as much as 10ºC. This decline in temperature may have been caused by a shutdown of the Gulf Stream, which usually carries warm water to Northern Europe. The Gulf Stream may have shut down because melting ice masses decreased the salinity and density of ocean water.

About predicting a future weakening of thermohaline circulation

An Intergovernmental Panel on Climate Change (IPCC) report predicts climate change will weaken thermohaline circulation. The principal contributor to such a slowdown is reported to be melting sea ice, which would increase the amount of fresh water in the North Atlantic Ocean. Higher concentrations of fresh water lower salinity levels, causing the water to be less dense and less likely to sink to the depths necessary to drive deep ocean currents.

Scientists do not agree on how significantly thermohaline circulation will be affected by climate change. Thermohaline circulation is driven by density differences, and water density is affected by temperature, precipitation, and evaporation. While there is general agreement in the scientific community about predicted temperature changes, scientists are not in agreement about precipitation and evaporation changes.

In June 2001, a team headed by Bogi Hansen, an oceanographer at the Faeroe Fisheries Laboratory, published a study showing what has happened in one passage of the North Atlantic Ocean over the past 50 years. The study, conducted near the Faeroe Islands, 400 miles east of Iceland, shows that the amount of cold water leaving the Norwegian-Greenland Seas has decreased 20 percent since 1948. The decrease is much more significant over the last five years of the study.

Image Credits

Image 5.1 — Timothy Folger and Benjamin Franklin
Image 5.2 — TERC
Image 5.3 — NASA Earth Observatory, Liam Gumley, MODIS Atmosphere Team, University of Wisconsin-Madison Cooperative Institute for Meteorological Satellite Studies
Image 5.4 — Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE
Image 5.5 — Lawrence Berkeley National Laboratory
Image 5.6 — Atlantic Oceanographic and Meteorological Laboratory, NOAA and Scripps Institute of Oceanography